2.4

EARTHQUAKE Hazards

ACTIVITY ONE

LIQUEFACTION: THAT SINKING FEELING

RATIONALE

Like other earthquake-related phenomena, liquefaction may cause the loss of property and even injury or death. This model allows instructors and students to observe the effects of liquefaction and the phenomenon of sand boils on a small scale.

FOCUS QUESTIONS

What happens when a damaging earthquake strikes areas prone to liquefaction?

OBJECTIVES

Students will:

1. Construct a model to demonstrate liquefaction.
2. Distinguish between soil liquefaction and soil saturation.
3. Assess potential damage to homes, lifelines, and schools.

MATERIALS

for the teacher

■Master 2.4a, Teacher Background Reading: Liquefaction

■Master 2.4b, New Madrid Narrative

for each small group

■226 g (about 8 oz) of well-sorted fine sand [Sandbox sand works well.]

■One .25-1 (9 oz) clear plastic cup

■One pie plate, diameter 23 cm (9 in.)

■225 ml (5 oz) of water in a pitcher

■Sinker or comparable small object weighing at least .06 kg (2 oz)

■One 250-ml beaker

■Newspapers to cover work surface

TEACHING CLUES AND CUES

If possible, substitute a small, hollow, ceramic house, measuring approximately 5 x 5 x 7 cm, for the sinker. These are sold at hobby shops for Christmas scenes, and can be filled with BBs to add weight.

PROCEDURE

Teacher Preparation

Read Master 2.4a, Teacher Background Reading: Liquefaction, and Master 2.4b, New Madrid Narrative. Decide how you will share this information with your students. Students who like to read will find New Madrid Narrative delightful.

Gather enough materials so you can have two students per station. Before class, cover work areas with newspapers, set up the stations, and practice each activity at least once to be sure everything works.

A. Introduction

Tell students that an earthquake with a magnitude of 5.0 or greater may cause saturated sand or clay soils to liquefy. During the winter of 1811 and 1812, a series of earthquakes affected the central por-tions of the United States that we now know as Missouri, Arkansas, Kentucky, Illinois, and Tennessee. As the soft sediments along the rivers were violently shaken, tremendous volumes of sand were liquefied and ejected onto the Mississippi River flood plain. These sand boils, as they are called, are still visible in the rural countryside today. Fortunately the area of the earthquakes was not heavily populated in 1811-12, so loss of life, injuries, and loss of property were minimal.

During the 1989 World Series in San Francisco, a 7.1 earthquake struck the Bay Area. Millions of people viewed firsthand the fires and severe damage to buildings in the Marina District. Some of this damage occurred because soil liquefaction caused lifelines to rupture and buildings to collapse.

B. Lesson Development

1. Write the word *liquefaction* on the board, and ask student to identify its root work (*liquid*). Emphasize that liquefaction does not cause an earthquake, but is the result of an earthquake. Liquefaction occurs only in highly saturated sand or clay soils. An earthquake with a magnitude of 5.0 or greater is usually needed to cause liquefaction. Earthquake vibrations cause soil particles to lose contact with each other, so the soil takes on the characteristics of a liquid.

2. Assign a partner to each student and designate a work station for each team. Give these directions:

a. Cut off about 5 mm from the bottom portion of the plastic cup.

b. Invert the cup and place it in the middle of the pie pan.

c. Holding the cup firmly, slowly pour the sand into the bottom of the cup to a level of 10-20 mm from the top. (One student may hold while another pours.) Level the sand with your fingers. *Do not shake the cup to settle or level the sand.*

d. Lightly place the sinker, model house, or other weight onto the leveled surface of the sand.

TEACHING CLUES AND CUES

Students may be aware that the flooding of the Mississippi and Missouri Rivers in the summer of 1993 caused mud boils in some places. Explain that these eruptions, somewhat similar to sand boils, were caused by extreme saturation of muddy soils in combination with the force of the torrential rains. Mud boils, like sand boils, can also be caused by earthquakes over magnitude 5.0.

VOCABULARY

Consolidated: tightly packed, composed of particles that are not easily separated.

Ground water: subsurface or underground water.

Lifeline: a service that is vital to the life of a community. Major lifelines include transportation systems, communication systems, water supply lines, electric power lines, and petroleum or natural gas pipelines.

Liquefaction: the process in which a solid (soil) takes on the characteristics of a liquid as a result of an increase in pore pressure and a reduction in stress.

Sand boil: a forcible ejection of sand and water from saturated soil, caused by an earthquake or heavy flooding.

Saturated: having absorbed water to the point that all the spaces between the particles are filled, and no more water can enter.

Unconsolidated: loosely arranged, not cemented together, so particles separate easily.

e. Again holding the cup, slowly pour the entire 225 ml of water into the pie pan around the outside of the cup and sand.

f. Observe what happens and record the time it takes for the soil to reach saturation.

g. Once the soil is saturated, one student win hold the cup firmly in place while the other gives the side of the cup several sharp taps to simulate earthquake shaking. Observe what happens to the weight.

C. Conclusion
Help students to clean up and then initiate the discussion. Ask: If the weight in our experiment were an occupied building, and liquefaction occurred over a large inhabited area, as it did in the San Francisco Bay Area in 1989, what would be the effect on:

- People?
- Private homes?
- Schools?
- Buried lifelines (gas, water, electrical, oil, sewage)?
- Agricultural lands?
- Medical facilities, fire stations, police stations?
- Large urban areas (Memphis, San Francisco, Boston)?
- Industrial areas?
- Materials that had been discarded in old sand boils? (These could range from dead cows to old refrigerators to poisonous waste.)

ADAPTATIONS AND EXTENSIONS

1. Make sand of various particle sizes and objects of different masses available for student experiments. Investigate the degree of liquefaction each will exhibit and the effects on the structures that rest upon them. (A layer of diatomaceous earth under the sand will bubble up when the table is rapped. Try it!)

2. Invite students to find ways to vary the amount of force they apply to the sand and water mix in the model.

3. Provide an aquarium or plastic gallon jars so students can experiment with larger models. Use transparent containers of any size—even a plastic sandwich box—for an interesting side view.

4. Bury objects in the sand and observe the results.

5. Develop models of overhead power lines, pipelines, sewage lines, light posts, and highways, and observe how liquefaction affects them.

6. Challenge students with this question: If a building has already been constructed on soil that has a potential to liquefy, what can be done to reduce the likelihood of damage? Invite them to design and test model structures that would reduce structural damage during liquefaction.

ACTIVITY TWO

LANDSLIDES: SLIP-SLIDING AWAY

RATIONALE

Earthquakes dramatically increase the potential for landslides in areas where landslides are common, such as those where sedimentary rocks lie just under the soil. Structures on cliffs and ridges need to be designed to the highest earthquake standards, and should be fully insured.

FOCUS QUESTIONS

How can an earthquake trigger a landslide?

What factors affect the probability of an earthquake-related landslide?

OBJECTIVES

Students will:

1. Construct a model to simulate an earthquake-related landslide.
2. Investigate the variables that affect an earthquake-related landslide, such as the strength of the slope materials, the steepness of the slope, and the intensity of ground shaking.
3. Explain why the steepness of a slope determines how the force of gravity acts on an area of ground and how it is related to frictional forces.

MATERIALS

for the teacher

- Slides or photos of landslide damage (in your geographic area, if available)
- Slide projector and screen or blank wall space (*optional*)
- Pasteboard or cardboard arrows in three colors, cut to the correct lengths to illustrate the 30° angle (*optional*)

for each small group

- A pine board, approx. 2.5 cm x 25 cm x 1.0 m (1 in. x 10 in. x 3 ft.)
- A meter stick
- Two plastic dishes, approx. 19 cm in radius, with sides 3.5 cm high
- Enough dry sand to fill the two dishes
- 500 ml of water in a beaker or other suitable container
- Newspapers to cover work surfaces
- A sensitive bathroom scale that can register weights as low as 1 Newton (less than 2 lbs)
- Paper towels for cleaning the board between trials
- Master 2.4c, Landslide Data Table
- Master 2.4d, Landslide Activity Sheet
- Pencils or pens

TEACHING CLUES AND CUES

The width of the board can vary, but it must be 1 m long.

The inexpensive clear plastic dishes sold to put under potted plants will be ideal. The dish must be a little smaller than the board.

- Transparency made from Master 2.4e, Components of the Force of Gravity
- Overhead projector
- Soil, gravel, or other materials for the extension (*optional*)

PROCEDURE

Teacher Preparation

Assemble slides and/or photos. Assemble the other materials ahead of time and experiment with them to get a feeling for how various angles will affect their movement. Cover work surfaces with newspapers.

A. Introduction

Ask the students: Can an earthquake cause a landslide? Promote a discussion of their experiences and ideas. Show any images you have gathered of earthquake-related landslides, especially those that have affected your local environment.

Explain to the students that not all landslides are earthquake related; many are caused by other natural factors. Landsliding, or mass movement, occurs when the forces that hold materials in place are exceeded by the force of gravity in the direction of motion. The forces that hold sand, soil, rocks, and buildings in place are related to the strength of the materials. The balance of these forces may be affected by the intensity of ground shaking during an earthquake. The steepness of the slope on which the materials rest determines how much the force of gravity acts in the direction of motion.

B. Lesson Development

1. Divide the class into cooperative groups of three or more students. Distribute one copy of Master 2.4c, Landslide Data Table, to each group. Ask one member from each group to collect a dish of sand and the other materials.

2. Tell the students they will be conducting this investigation in a scientific manner. That is, they are to control the variables, manipulate only one, and measure or observe the response. When students have completed the experiment, it is very important that they use only their results to develop an explanation and that their explanation relates only to this particular model. Point out that the questions toward the end of the Landslide Activity Sheet relate to the scientific process they are employing.

3. Instruct students to set up a ramp, as illustrated on Master 2.4c, and begin to explore the effect of the ramp's angle on the weight the scale reads. Explain that the less weight the scale records, the greater the force of gravity parallel to the ramp and the weaker the force of friction that holds the material in place. Give these instructions:

a. Place the scale at the bottom end of the ramp and place a dish of sand right side up on top of it.

b. Raise one end of the ramp to the height corresponding to the first angle indicated on the Landslide Data Table. As you move from one angle to another, record the scale readings in the Landslide Data Table.

VOCABULARY

Friction: mechanical resistance to the motion of objects or bodies that touch.

Gravity: the force of attraction between any two objects with mass. Gravity is especially noticeable when an object of great mass, such as Earth, attracts an object of lesser mass.

Landslide: an abrupt movement of soil and bedrock downhill in response to gravity. Landslides can be triggered by earthquakes or other natural causes.

Loess: an unstratified, windblown mixture of clay, sand, and organic matter usually crumbly and buff or yellow-brown in color.

Mass movement: the movement of surface material caused by gravity.

Variable: in a scientific experiment, the one element that is altered to test the effect on the rest of the system.

TEACHING CLUES AND CUES

If you do not have enough scales you may do this section as a demonstration. You may also choose to simply describe the forces and use the factors in the data table below to describe how the measured weight of the material changes as the angle of the ramp changes. Whether you do the weighing or the students do, be sure to convert pounds into the metric unit Newtons (2.2 pounds = 9.8 Newtons).

4. Stop the groups when they have completed the scale measurements and explain that the ramp breaks the force of gravity up into two components. Project the transparency of Master 2.4e, Components of the Force of Gravity, to illustrate. One of the components operates in a direction perpendicular to the ramp; that is the force they just measured. The other force operates along the ramp. That is the force of gravity, which will cause the landslide. These two components of gravity form two sides of a right triangle. Depending on the angle of the ramp, the force of friction may or may not cancel the force of gravity.

5. To investigate the effect of slope on material with and without a simulated earthquake, ask the students to remove the scale. Show them how to place the dish of sand upside down at one end of the board without spilling the sand. First, place the board on top of the dish. Then, while holding the board down over the dish, carefully flip the board over. The dish should be upside down on the board with all the sand still in the dish.

6. When all the groups have accomplished this, ask students to vary the angle of the ramp as they did before, this time by slowly raising the end of the board with the dish of sand. Instruct students to record the height at which the sand starts to slide, then lower the ramp by about 5 cm and tap on the ramp to simulate an earthquake.

7. Give these instructions to test the effect of water on the sand:

a. Again cover the dish with the board, flip the dish right side up, and add 225 ml of water to the sand.

b. Flip the dish of wet sand back onto the ramp and repeat step 6 to see the effect each new angle of the ramp has on the wet sand.

c. Continue to record your data and observations in the Landslide Data Table. Use the transparency of Master 2.4e, Components of the Force of Gravity, and Master 2.4d, Landslide Activity Sheet to answer the questions about force.

C. Conclusion

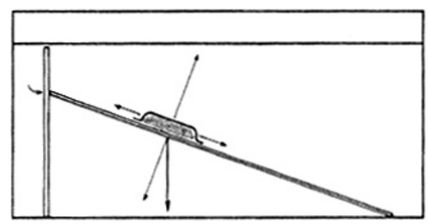
Allow time for students to respond to the last questions on the Landslide Activity Sheet, which ask them to develop an explanation for what they have observed. When they have finished, ask the groups to share their explanations, being certain to justify their explanations by citing their data.

Ask the class if they think the work they have just done is similar to what scientists do. Ask them what the scientific community would do with a variety of explanations and varying data for the same procedure. Impress upon students that their investigation is one aspect of science and their reporting is another. Explain that it would take a great deal of time and many replications for any of their explanations to be accepted as a landslide theory. If they try the extension activities and want to carry their investigation of landslides still further, they will have to connect this model to real landslide data.

TEACHING CLUES AND CUES

If you made the arrows listed in the materials section, use them now to help students visualize these angles. Explain that the science of trigonometry deals with the mathematics of right triangles. Here you will simply measure and calculate the forces.

From 0-20 degrees not much will happen, but above 20 degrees, the students should begin to see some distinct motion.



Finally, review and summarize the forces involved in landslides, referring to the illustrations on the handouts. Show the photos or slides again, and ask students to explain what they observe in terms of physical forces.

ADAPTATIONS AND EXTENSIONS

Invite students to test the effect of the material by repeating steps 6 and 7 above with dishes of potting soil, gravel, and other materials.

ACTIVITY THREE

TSUNAMI: WAVES THAT PACK A WALLOP

RATIONALE

Underwater earthquakes can cause very powerful seismic sea waves commonly called tsunami or (incorrectly) tidal waves. These waves can devastate a coastal community because of the tremendous amount of energy they carry.

FOCUS QUESTIONS

How do earthquakes cause seismic sea waves?

What kinds of energy transfers are involved?

What precautions can people take to limit tsunami damage?

OBJECTIVES

Students will:

1. Prepare and present a class report that reflects their own research on seismic sea waves.

2. Describe the characteristics of an average seismic sea wave in terms of speed, wavelength, and period, and predict its effects on a coastal community.

3. Calculate the energy of the disturbance (sea floor motion) that causes an average seismic sea wave.

MATERIALS

- Master 2.4f, Teacher Background Material
- Student copies of Master 2.4g, Tsunami Event Reports
- Student copies of Master 2.4h, Seismic Sea Waves Activity Sheet
- Transparency of Master 2.4i, Wave Characteristics and Energy
- Overhead projector
- Student copies of Master 2.4j, Seismic Sea Waves Energy Analysis
- Copies of Master 2.4k, Seismic Sea Waves Research and Report Form, one for every two students
- A large coil, telephone cord, or hose for demonstrating wave action
- Numerous student copies of Master 2.41, Grading Matrix

VOCABULARY

Amplitude: a measurement of the energy of a wave. Amplitude is the displacement of the medium from zero or the height of a wave crest or trough from a zero point.

Period: the time between two successive wave crests.

Run-up elevation or height: the highest attitude above the tide line, in meters, that the water reaches as it is forced up on land by a tsunami.

Seismic sea wave: a tsunami generated by an undersea earthquake.

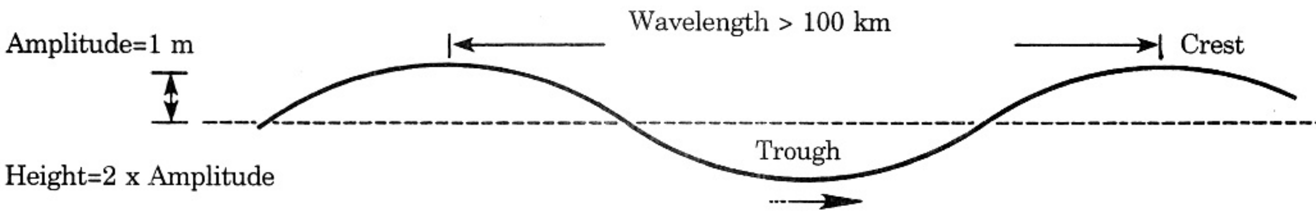
Tsunami: a potential destructive ocean wave created by an earthquake or other large-scale disturbance of the ocean floor. This Japanese word has the some form in both the singular and the plural.

Wave crest: the highest point a wave reaches. The lowest point is called its *trough*.

Wave height: the vertical distance in meters from a wave's crest to its trough. (This measurement will be twice the amplitude measured for the some wave.)

Wavelength: the horizontal distance between two successive crests, often measured in meters.

- Poster board or chart paper, markers, and audiovisual equipment as available
- Video camera (*optional*)



PROCEDURE

Teacher Preparation
Read the teacher background information on tsunami. Locate some before and after photos of tsunami, and either make transparencies or have them available to pass around the room.

Check your school and community libraries for the periodicals listed at the end of this lesson and in the Unit Resources. Also look for beginning oceanography textbooks and back issues of *Scientific American*.

A. Introduction
If you have photos, share them with the class. Then pass out copies of Master 2.4g, Tsunami Event Reports. Have students take turn reading the accounts aloud. Ask students what they think causes tsunami.

B. Lesson Development
1. To provide the students with some common language, pass out Master 2.4h, the Seismic Sea Wave Activity Sheet, and help the class work through it. Project the upper half of Master 2.4i, Wave Characteristics and Energy. Ask students to tell you what belongs in each blank, and label the wave form accordingly. Point out that waves never stand still, so we have to be very clever to measure their characteristics.

2. Pose this question: How can a fault movement of only one meter in the depths of the ocean cause a huge wave to strike land? Promote student discussion until someone mentions the energy involved. At that point, project the lower half of Master 2.4i, and show students how the uplift of one meter actually involves lifting a column of water the same size as the area of seafloor uplifted.

3. Pass out copies of Master 2.4j, Seismic Sea Waves Energy Analysis. Work through the activity as a class or have students complete the worksheets in pairs, depending on their previous preparation.

TEACHING CLUES & CUES


You may want to review scientific notation before handling the large numbers in this activity.

4. Challenge students to explain how a wave that is only one meter high in the ocean can grow so high as to overwhelm the land. Again direct their attention to the lower half of 2.4i, and point out the energy involved. (As the wave nears shore, in shallow water, the energy is forced upward, or refracted. See Master 2.4f for more detail.)

5. Invite students to do some research on actual tsunami drawn from the table of Notable Tsunami (below) or from other sources. Hand out one Seismic Sea Waves Research and Report Form (Master 2.4k) to every two students, explaining that each team is to research a specific topic and report what they learn to the class. Two students will report on tsunami warning systems; the others will report on a particular tsunami drawn from the list below. Set a due date and establish how you are going to evaluate the report. If you will use the matrix provided, explain it now.

Notable Tsunami by Place Reported

November 1, 1755	Lisbon, Portugal
April 2, 1868	Hilo, Hawaii
June 15, 1896	Sanriku, Japan
August 13, 1868	Arica, Peru
August 27, 1883	Java, eruption of Krakatau (also spelled Krakatoa)
March 2, 1933	Sanriku, Japan
April 1, 1946	Hilo, Hawaii
March 9, 1957	Hilo, Hawaii
May 23, 1960	Southern California
March 28, 1964	Crescent City, California
November 29, 1975	Hilo, Hawaii
May 26, 1983	Minehama, Honshu, Japan
July 12, 1993	Aonae, Japan

6. Invite discussion of preventive measures that can be taken to minimize seismic sea wave damage. As students progress in their research, they may be able to suggest guidelines. The presentations on early warning systems will address this topic directly.

7. When the due date for presentations is near, review how you will evaluate the presentations and specify the time limit for each. Provide poster board or chart paper and markers, overhead transparencies and pens, and slide or video apparatus if available.

C. Conclusion

Have the students present their reports. Before each presentation, distribute copies of the grading matrix. Ask students to use one matrix sheet for each presentation, taking notes in the space allotted and evaluating their peers' presentations on the same criteria by which theirs will be graded. A respectful classroom atmosphere will ensure the success of these presentations.

TEACHING CLUES & CUES

You may want to videotape the presentations by setting the camera up on a tripod very close to the presenters. If you film your first class, you can use the footage to show other classes what you are looking for.

ADAPTATIONS AND EXTENSIONS

Challenge one pair of students to research and describe the compressional waves that have been associated with underwater earthquakes in terms of the wave's characteristics and its effect on ships. ▲

How Liquefaction Occurs during Quakes

Liquefaction happens during an earthquake when vibrations cause the pressures to build up in the ground water that occupies the pore spaces between the grains of sand, silt, or loess. The longer the duration of the earthquake, the more likely that liquefaction will be induced. The only solid strength of such a deposit is provided by the friction between grains touching each other. When the pressure in the water that fills the pore space between the grains is sufficient to spread them apart, the solid nature of the sand, silt, or loess deposit is changed into that of a viscous liquid: "quicksand" or "quickclay."

Because it takes time for the pressures that produce liquefaction to build up underground, and because quicksand is a heavy, thick fluid that moves slowly, conditions of liquefaction, sand boiling, and associated phenomena may not he apparent during the shaking. In fact, they often do not manifest until after the shaking has already passed, sometimes not until 10-20 minutes later. The quick conditions or boiling of the sand can persist for hours or even days after the quake, sometimes as much as a week.

How Big Does It Take & How Near to the Quake?

A natural question regarding seismically induced liquefaction is how big an earthquake is required to induce quick conditions and how close it has to be for such effects to be possible. With regard to size, several technical publications suggest that liquefaction does not occur for earthquakes less than Richter magnitudes of 5.2. However, minor liquefaction effects in areas underlaid by particularly ideal predisposing conditions (loose sand deposits saturated with a near-surface water table) have been observed for earthquakes as small as 4.7 on the Richter scale in the New Madrid Seismic Zone. Minor damage to vulnerable structures has occurred in such areas.

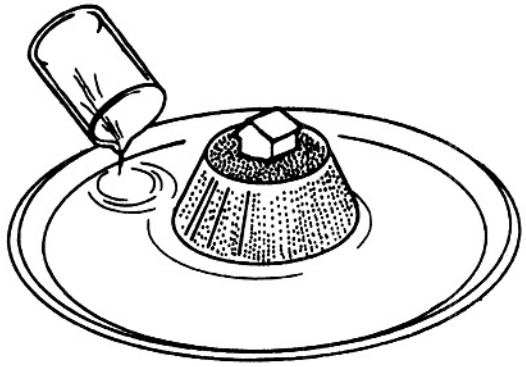
With regard to distance, an earthquake in June of 1987 of magnitude 5.2 in southeastern Illinois caused liquefaction phenomena near Bell City, Missouri, 150 miles (240 km) from the epicenter. A swimming pool, two large grain bins, a carport, and three houses were damaged (one severely). There was also fissuring and lateral spreading. At the same time, points nearer the epicenter of that quake did not experience such ground failures. Three years later in 1990 this same area experienced no liquefaction phenomena when a 4.7 earthquake struck only 20 miles (32 km) away.

Nearness to the epicenter implies greater amplitudes of ground motion, but distance implies a longer duration of shaking, since the wave train consists of many waves traveling at a variety of speeds. The epicenter of the magnitude 8.1 earthquake that struck Mexico City in 1985 was 240 miles (384 km) away and induced liquefaction that severely damaged some buildings. Although lasting less than a minute at its distant source, that quake lasted several minutes in Mexico City. Ground shaking amplitudes within the city, were never large, yet 400 buildings collapsed, resonating with the long-lasting wave train (or sequence of waves) amplified by underlying clays.

The New Madrid earthquakes of 1811-12 induced extreme examples of liquefaction, manifesting as sand boils and explosion cratering in the area of St. Louis, Missouri, and across the river in the flood plain of Illinois. Liquefaction also occurred from those quakes as far as Cincinnati, Ohio, more than 300 miles (480 km) away.

Three Ways to Induce Liquefaction

Liquefaction in soils can be stimulated three ways: seismically, mechanically, and hydrologically. Seismically-induced liquefaction is caused by seismic waves. Mechanically-induced liquefaction is caused by vibrations that come from railroad trains, motor vehicles, tractors, and other mechanical sources of vibratory ground motion. Hydrologically-induced liquefaction occurs when ground-water pressures increase due to rising stream levels



during flooding conditions. This type of liquefaction most commonly occurs on properties protected by levees, where rivers can rise to levels above the land surface without actually flooding the land. Most of the New Madrid Seismic Zone falls into this category, being surrounded by levees that flank the rivers and drainage ditches throughout the area. Because of this, seismically-induced sand boils became hydrologically active during river flood stages, and can turn into quicksand and boil again, just as they did during the earthquakes that formed them. Similarly, tractors, trains, and trucks crossing over sand fissures during times of high water table can mechanically induce liquefaction, causing highways to sag, railroad tracks to get out of parallel, and farm equipment to sink into the ground.

Note: *Adapted from Stewart, David, and Knox, Ray,* The Earthquake That Never Went Away: The Shaking Stopped in 1812, but the Impact Goes On, *Marble Hill, MO: Gatlinburg-Richter Publications, 1993*.

New Madrid Narrative

(A 1912 Account of the 1811-1812 Earthquakes)

The First Day
At 2:30 on the morning of December 16, 1811, a tremendous earthquake occurred whose epicentral region is thought to have been just west of the location of present day Blytheville, Arkansas, a city that did not exist at the time. Had it been there, it would have been devastated totally, as evidenced by the numerous earthquake boils and fissures that visibly surround the city today. The Richter surface wave magnitude is thought to have been 8.6. President James Madison, 800 miles (1280 km) away in the White House in Washington, DC, was shaken out of bed by the quake.

Many aftershocks immediately followed, some probably magnitude 6.0 or greater. At least two more of the December 16 shocks are thought to have equaled 8.0 on the Richter scale.

Then, some time around 11:00 a.m., another great shock occurred in the vicinity of present-day Caruthersville, which to the residents there at the time seemed worse than the first. This one is thought to have been another magnitude 8.0. However, present-day Caruthersville wasn’t there at the time. It was not founded until 1857. In 1811 another village occupied that site. It was called Little Prairie, Missouri.

The River Rampages, and Towns Disappear
The Mississippi River was churned into a virtual maelstrom, with miles of banks caving in, boats being swamped and sunk, and even entire islands disappearing along with their human occupants.

Two towns disappeared at this time. One settlement to disappear on December 16, 1811, was Big Prairie, Arkansas. At the confluence of the Mississippi and St. Francis Rivers, the town site liquefied and sank, but slowly enough for all residents to safely escape. There were about 100 people there at the time. The Mississippi River now occupies that site.

Another community destroyed that day was Little Prairie, Missouri, near present-day Caruthersville. Eyewitness accounts of the horror tell us of people being violently thrown from their beds in the middle of the night. It had been a bright full moon, but shortly after the shock everything became pitch black because of the dust. People were injured and bleeding, and some were even knocked temporarily unconscious.

The earth continued to jerk and rumble through the darkness until daylight, when, around 8:00 a.m. the second hard shock hit the area. Throughout the morning more shocks continued, with the ground heaving and cracking, sometimes opening and then suddenly slamming shut, spewing ground water over the tops of tall trees. In some places the ground literally exploded, blasting debris high into the air, raining sand and carbonized wood particles down upon the heads of those nearby, while leaving a deep crater in the ground where smooth land had been before. Sometimes the earth formed spreading crevasses beneath the bases of large trees, splitting their trunks from their roots upwards beyond the levels of their limbs. At one point during the morning a great fissure began to form within the town. The townspeople stood around that pit and watched, horrified, as dark, viscous fluids gurgled from beneath the earth while gaseous fumes and the smell of sulfur and brimstone filled the air.

Many were thinking that the end of the world was at hand and that the very gates of hell itself were opening up to take their village. Amidst the terror, after the third great shock around 11:00 a.m., the soils of their settlement began to turn into quicksand, with dark waters oozing from the pores of the earth. As their whole town began to sink their streets and cabins were flooded, not from the river, but from the ground itself.

Escape from Little Prairie
Hastily, the residents of Little Prairie gathered what meager possessions they could hold, lifted small children to their shoulders, and waded westward. Looking ahead of themselves, they could see the rising waters far off on the horizon. For eight miles (12.8 km) they waded through waist-deep waters, never knowing from one step to the next if they were going to plunge headlong into an unseen crevasse or trip over a buried stump, all the while surrounded by snakes, coyotes, and other wild creatures swimming for their lives in that turgid flood. During their escape, they did not know if they would live through the day or not, but all did survive.

The First Day Was Over, but the Worst Was Yet to Come
What has been described, thus far, was only the first day of the Great New Madrid Earthquake series. More and bigger tremors were yet to come. At about 9:00 a.m. on January 23, 1812, another of the really big ones hit. This was probably centered north of Little Prairie and south of Point Pleasant, a small settlement there at the time. It is thought to have been an 8.4 magnitude earthquake.

The Mississippi River bank, on which the village of Point Pleasant was situated, collapsed during the January 23 event. Fortunately, the residents had all evacuated the site prior to that catastrophe so that none were injured. The town, however, was lost forever.

The January 23 event also caused several huge sand boils in Tennessee that created a dam across Reelfoot Creek. This created "Reelfoot Lake."

On February 7, 1812, came the largest quake of all. At about 3:15 in the morning the region was rocked by an 8.8 magnitude shock. Outside of Alaska, that is the largest earthquake in American history and one of the largest in the world.

This is the quake that caused the Mississippi River to run backwards. It caused such towering waves of water to be thrown over the banks that thousands of acres of trees were shattered into splinters and stumps. It threw boats up on dry land along St. John's Bayou at New Madrid. And it created two temporary waterfalls. These falls had a vertical drop of about six feet (2 m) followed by a mile (2 km) or so of shallow rapids.

During the largest of the New Madrid earthquakes, the river is said to have boiled, whirled, and heaved with massive waves bashing from one bank to the other, sweeping boats and debris into oblivion. Some eyewitnesses from the banks said they actually saw the river open up in yawning chasms, into which the swirling waters disappeared, drawing hapless flat boats and their passengers into the maelstrom, never to be seen again. Others said water spouts would shoot upwards from the waters surface, like tall fountains.

The earthquakes had literally destroyed the landscape with sand deposits, crevasses, and permanent flooding. Most residents of the region abandoned their properties and moved away. The boot-heel portion of Missouri was nicknamed "Swampeast Missouri" sometime after the quakes.

Two More Towns Gone Forever

The February 7 quake destroyed two other towns, wiping them forever from the face of the earth. One was Fort Jefferson, Kentucky, swept away by landslides. These slumps are still visible today along Highway 51 leading into Wickliffe. The other lost town was New Madrid itself. What was left of the settlement slumped downward 15-20 feet (5-10 m) into the water's edge and was washed away by the spring floods of 1812.

The throbs and throes of terra firma wrought by the Great New Madrid Earthquakes of 1811-12 trouble us no more. Though the motions of these gargantuan ground vibrations ceased in 1812, their impact goes on. Permanent traces of their violence lie scattered over a 5,000 square mile (12,000 sq km) area spanning five states.

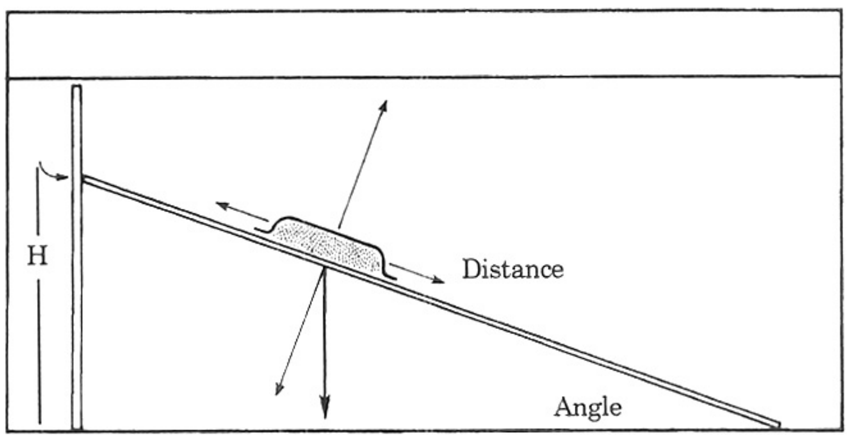
Note: *This account was adapted with only minor changes from Fuller, Myron L.,* The New Madrid Earthquakes of 1811-1812*,* A Scientific Factual Field Account, *USGS Bulletin 494, Washington, DC: Government Printing Office, 1912; reprinted by Southwestern Missouri University Center for Earthquake Studies, 1990. Please keep in mind that the numerical Richter magnitudes quoted in this book were not determined by instrumental measurements as they are today, because these events predated the invention of reliable seismographs.*

Landslide Data Table

Name ____ Date ____________________

Ramp and Force Measurements

Angle	Height	Force
10°		
20°		
30°		
40°		
50°		
60°		



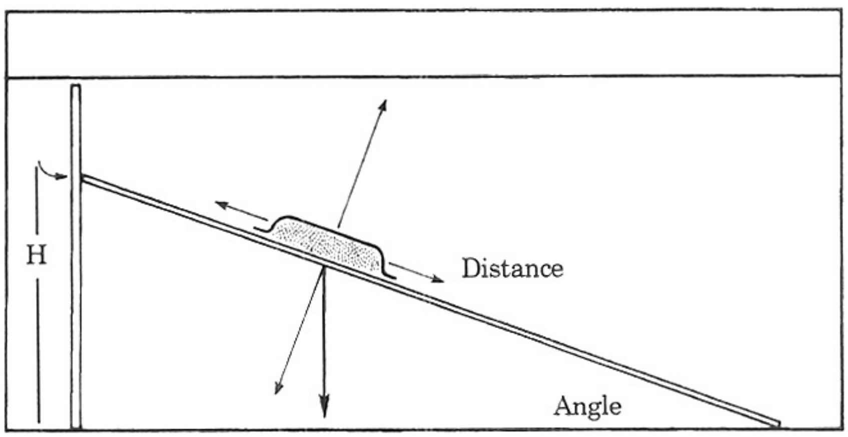
Effect of Height on Materials

Material	Angle	Height	Effect of simulated earthquake (1 tap)
Dry Sand			
Wet Sand			
Dry Soil			
Wet Soil			
Other			
Other			

Landslide Data Table (key)

Ramp and Force Measurements
(Note: answers will vary)

Angle	Height	Force
10°	17 cm	
20°	34 cm	
30°	50 cm	
40°	64 cm	
50°	77 cm	
60°	87 cm	



Effect of Height on Materials
(Note: answers will vary)

Material	Angle	Height	Effect of simulated earthquake (1 tap)
Dry Sand	30°	40-50 cm	Sand moved about 1 cm per knock
Wet Sand	30°-40°	55-65 cm	Sand moved about 2 cm per knock
Dry Soil	30°-40°	50-60 cm	Sand moved about 1 cm per knock
Wet Soil	30°-40°	50-60 cm	Sand moved about 2 cm per knock
Other			
Other			

Landslide Activity Sheet

Name ____ Date ____________________

Group Names/Roles

______________________ ______________________

______________________ ______________________

1. Why do you think the scales measure less weight as one end of the ramp is raised?

2. At what height or what angle does the dry sand slide?

Why do you think it slides then, in terms of forces?

3. What effect does the simulated earthquake (knocking on the ramp) have on the dry sand?

Why do you think the simulated earthquake has that effect?

4. Before testing wet sand, what effect do you think wetting the sand will have on the slide angle? Why?

5. What effect did wetting the sand have on its slide angle? Why?

6. What effect does the simulated earthquake (knocking on the ramp) have on the wet sand?

7. How did you control the following variables?
a. height or angle

b. quantity of material

c. amount of moisture

d. surface condition

e. other

8. How did you insure that only one variable was changed at a time?

9. From your data, try to explain how earthquakes affect landslides in as much detail as possible.

10. How could you test your explanation?

11. What was interesting or unexpected in the investigation? Why?

Landslide Activity Sheet (key)

Date:

1. Why do you think the scales measure less weight as one end of the ramp is raised?
   Some of the weight is acting along the ramp. The scale doesn't record that weight.

2. At what height or what angle does the dry sand slide?
   40-50 cm, or about 30 degrees.

   Why do you think it slides then, in terms of forces?
   The force of gravity along the ramp is greater than the frictional forces.

3. What effect does the simulated earthquake (knocking on the ramp) have on the dry sand?
   The sand slides a bit with each knock.

   Why do you think the simulated earthquake has that effect?
   It must reduce the frictional forces because gravity remains constant.

4. Before testing wet sand, what effect do you think wetting the sand will have on the slide angle? Why?
   It will probably slide more easily because the water reduces the friction.

5. What effect did wetting the sand have on its slide angle? Why?
   The sand seemed to stick to the ramp, so it required a sharper angle to make it slide.
   Surface tension causes the sand to adhere to the ramp.

6. What effect does the simulated earthquake (knocking on the ramp) have on the wet sand?
   It slid further with each knock.

7. How did you control the following variables?
   a. height or angle
      Used a meter stick according to the table.

   b. quantity of material
      Filled the dish full each time.

   c. amount of moisture
      Measured 225 ml.

   d. surface condition
      Used only one type of sand.

   e. other

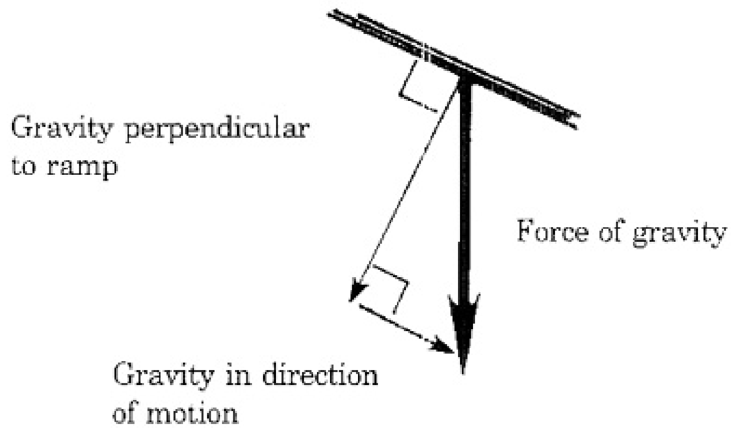
8. How did you insure that only one variable was changed at a time?
   We carefully observed and recorded after each change.

9. From your data, try to explain how earthquakes affect landslides in as much detail as possible.
   An earthquake will cause a "slidable" piece of material to move a certain amount for each jolt.

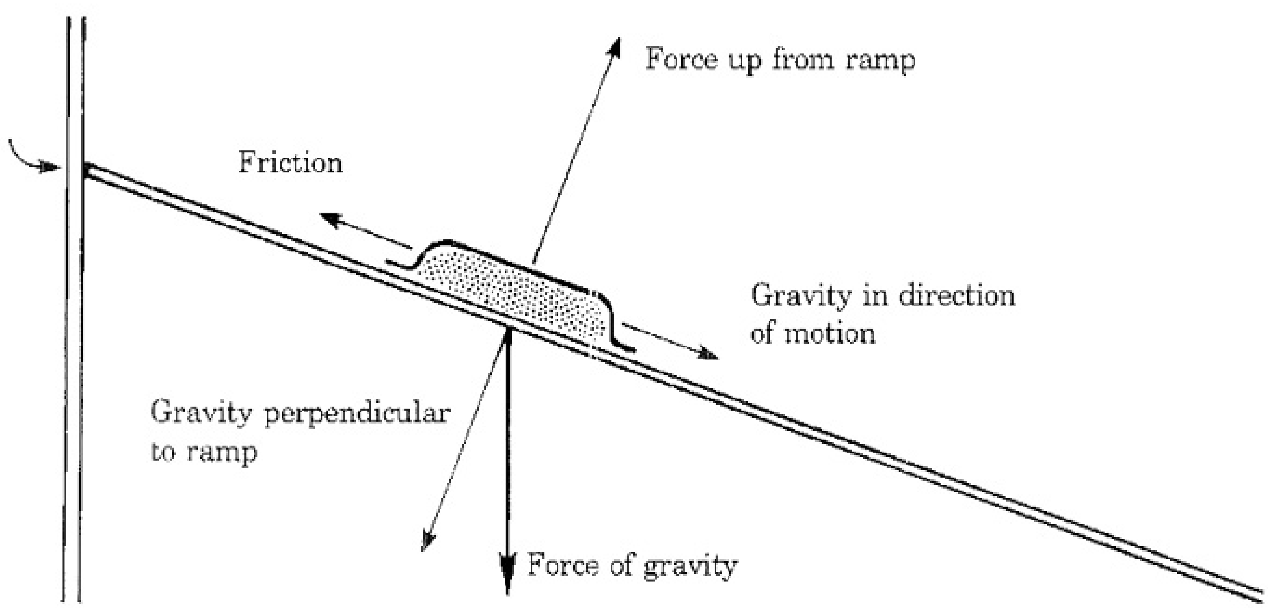
10. How could you test your explanation?
    Repeat the investigation. Compare our explanation to others. Look into real landslide data.

11. What was interesting or unexpected in the investigation? Why?
    The addition of water did not lower the angle required for the sand to slide.

Components of the Force of Gravity



Components of the Force of Gravity



Force Analysis When Not Moving

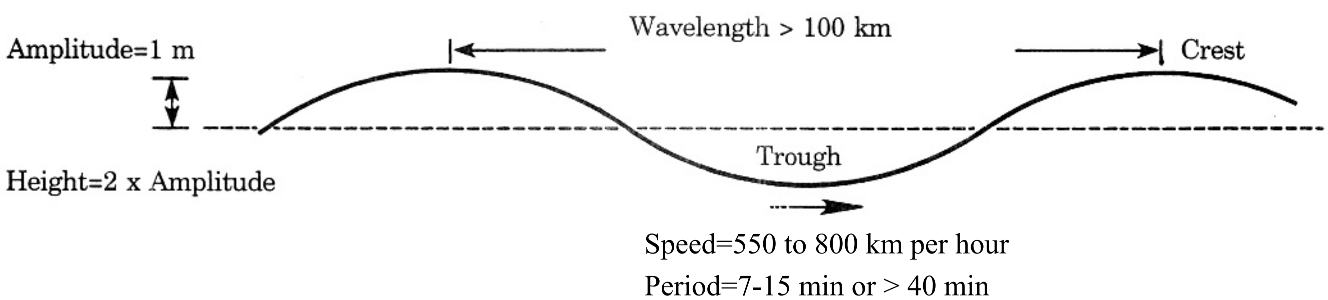
Teacher Background Reading
Seismic Sea Wave

A seismic sea wave is created when a fault in the ocean floor moves vertically. The energy of the lifted or lowered water radiates outward as very long shallow water waves commonly (and erroneously) called "tidal waves." Because these waves have nothing to do with the attraction of the Moon or the Sun, scientists prefer the Japanese word tsunami, which means "wave in the harbor," or the English term seismic sea wave.

Most seismic sea waves, like most earthquakes, occur around the Pacific Ocean, but there have been great seismic sea waves in most regions of the Earth.

The great destructive power of these waves comes from the huge energy imparted to the water by fault movement. To equate this energy to mechanical work, we can imagine the work needed to lift an average volume of ocean water a distance (d) of 1 meter. The average depth of the ocean (h) is 3.8 km. The average surface area (A) of the ocean floor moved up or down by such an event, according to seismic sea wave research, is 20,000 square kilometers—a 200 km x 100 km piece of seafloor about the size of New Jersey. The volume (V) of seawater lifted would then be 76,000 cubic kilometers. If we take 1.03 kg/m^3 as the density (D) of seawater, the mass (m) of that seawater would be about 78 billion metric tons. To lift this much water by 1 m would take 7.6 x 10^{14} Joules, the energy of 183 kilotons of TNT. See Master 2.4j for a complete quantitative analysis.

This energy radiates outward from the epicenter as a wave train of low waves, not as a single large wave. Each of these seismic sea waves has an average amplitude of 1 meter, wavelengths over 100 km, and periods of 7-15 minutes (for short-period tsunami) or over 40 minutes (for long-period tsunami). These waves travel at speeds between 550 and 800 kilometers per hour before encountering land.



Seismic Sea Wave Characteristics

Seismic sea waves are very different from wind-generated sea waves. Normal wind waves rarely have wavelengths over 300 meters, and generally travel under 100 km/hr. A medium-sized tsunami can have wavelengths of 150 km and travel at 550–800 km an hour. Tsunami are like tides in that a low tide is followed by a high tide, but in the case of a tsunami dramatic high and low tides can be only tens of minutes apart. This may be the origin of the expression tidal wave.

As seismic sea waves encounter land, they cause rapid tide-like motion. The trough of the waves causes very low tides, while the wave crests may cause a run as high as 32 meters. Sometimes seismic sea waves can cause enormous breaking waves. The mechanism for these waves is very similar to that of wind waves; the friction of the ocean bottom slows the troughs and the crests move over them and break. Thus the characteristics of seismic sea waves when they hit land, like those of wind waves, are very much related to the characteristics of the near-shore ocean bottom and the shoreline.

The depth of the ocean water also controls the speed of seismic sea waves. As the depth changes, the wave's speed and direction change, resulting in the phenomenon we call refraction—the change in direction of a wave as it moves from one medium to another.

Extensive international cooperation has developed a tsunami early warning system for the Pacific Islands. A system for the U.S. Pacific Coast is being developed. The older system is centered at the Pacific Tsunami Warning Center in Honolulu, where data are collected from seismic observatories across the globe. The Center evaluates the potential of a tsunami and institutes special observations at various tsunami watch stations. All these data are verified and emergency preparation procedures are put into effect when necessary.

Causes Other Than Earthquakes

Not all destructive sea waves are caused by earthquakes. Some are caused by landslides and volcanic eruptions and some are artificially created by events like underwater nuclear explosions. In 1883, the Krakatoa Island volcano erupted, blowing the island away down to a depth of about 43 m below sea level. This event caused giant waves that killed some 36,000 people in Java and Sumatra.

Tsunami Event Reports

1. On July 12, 1993, the Hokkaido-Nansei-Oki earthquake of magnitude 7.8 produced one of the largest seismic sea waves in Japan's history. The tsunami hit the Okushiri coast within five minutes after the main shock, causing waves at the shoreline between 15 and 30 m high. The town of Aonae on the island of Okushiri suffered extensive damage. At least 185 people were killed, with property damage estimated at $600 million.

2. The Prince William Sound, or Anchorage, Alaska, earthquake of March 27, 1964, caused seismic sea waves generated by an underwater landslide. At Valdez, the earthquake triggered a landslide that deepened the harbor by as much as 100 m in one place and caused a tremendous tsunami. In addition, the earthquake uplifted the sea floor by as much as 4 meters. The tsunami killed 119 people in Alaska, Hawaii, and California and caused over $282 million in damage.

3. On April 1, 1946, at 53.5º north and 163º west, 130 km southeast of Unimak Island, Alaska, a large earthquake occurred 4,000 m below the ocean surface in the Aleutian Trench, causing an undersea landslide. Four and one half hours later, a tsunami reached Oahu, Hawaii, after traveling 3,600 km at 800 km/hr. Water rose 12 m above the high tide line on Oahu and 18 m on Hawaii (the "Big Island"). This seismic sea wave demolished 488 homes and damaged 936 others, with property loss estimated at $25 million and 173 people killed.

4. An earthquake on the ocean floor may also cause a compressional wave that can severely damage ships close to the epicenter of the event. Even though we consider fluids as non-compressional in systems like automobile brakes, compressional waves can travel in seawater under the tremendous pressures and accelerations of the water in underwater seismic events. Ships struck by these waves report an experience similar to running aground or striking another vessel.

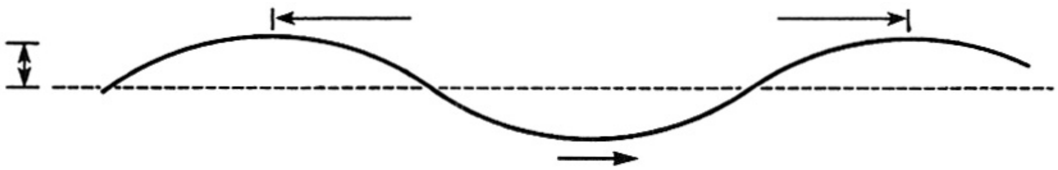
In 1969, a magnitude 8.0 earthquake west of Gibraltar caused compressional waves that struck the 32,500-ton tanker *Ida Knudsen*, sailing in 4,900 m of water. The tanker was 35 km from the epicenter of the seaquake and suffered so much damage that at first it was declared a total loss. The ship was later extensively rebuilt.

Seismic Sea Waves Activity Sheet

Name ______________________________ Date ______________

Characteristics of a Seismic Sea Wave

Label the following characteristics and state the average values.



A Possible Tsunami Scenario

Imagine that a magnitude 6.8 earthquake occurs 1,625 km from a coastal town on a strike-slip fault in the ocean floor, where the water is 3.8 km deep. A wave train is generated with a speed of 650 km/hr and wavelengths of 150 km. The National Tsunami Warning Center alerts the townspeople.

1. How long will it take the tsunami to hit the coastal town?

____

2. The first wave hits at 2:00 p.m. Does Jen have time to rescue the boom box left on the beach before the next wave hits? Calculate the period of the waves. (Period is wavelength divided by speed.)

____

____

3. Describe what might happen when this seismic wave encounters the coastal town.

____

____

____

____

4. What could be done to prepare for this tsunami?

____

____

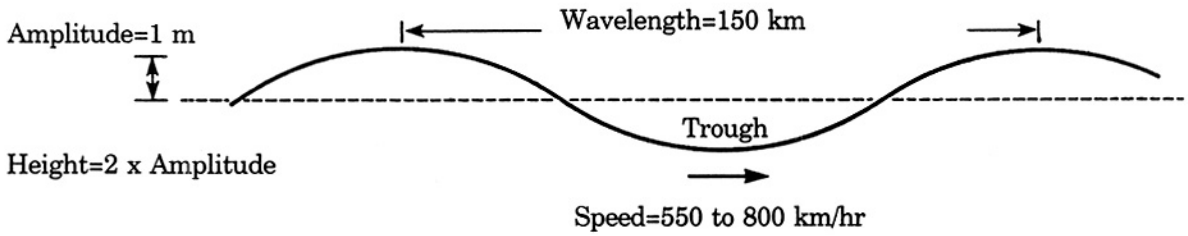
____

____

Seismic Sea Waves Activity Sheet (key)

Characteristics of a Seismic Sea Wave

Label the following characteristics and state the average values.



A Possible Tsunami Scenario

Imagine that a magnitude 6.8 earthquake occurs 1,625 km from a coastal town on a strike-slip fault in the ocean floor, where the water is 3.8 km deep. A wave train is generated with a speed of 650 km/hr and wavelengths of 150 km. The National Tsunami Warning Center alerts the townspeople.

1. How long will it take the tsunami to hit the coastal town?

Time = Distance / Speed = $\dfrac{1{,}625 \text{ km}}{650 \text{ km / hr}}$ *= 2.5 hours*

2. The first wave hits at 2:00 p.m. Does Jen have time to rescue the boom box left on the beach before the next wave hits? Calculate the period of the waves. (Period is wavelength divided by speed.)

Period = Wavelength / Speed = $\dfrac{150 \text{ km}}{650 \text{ km / hr}}$ *= .23 x 60 = 13.8 min*

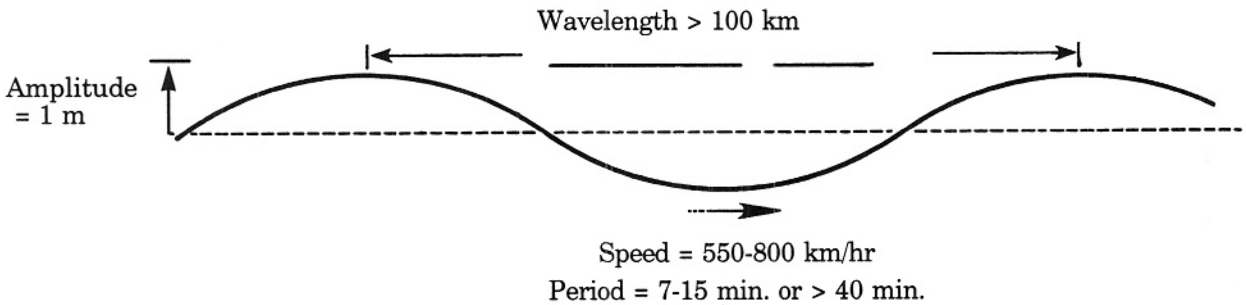
3. Describe what might happen when this seismic wave encounters the coastal town.

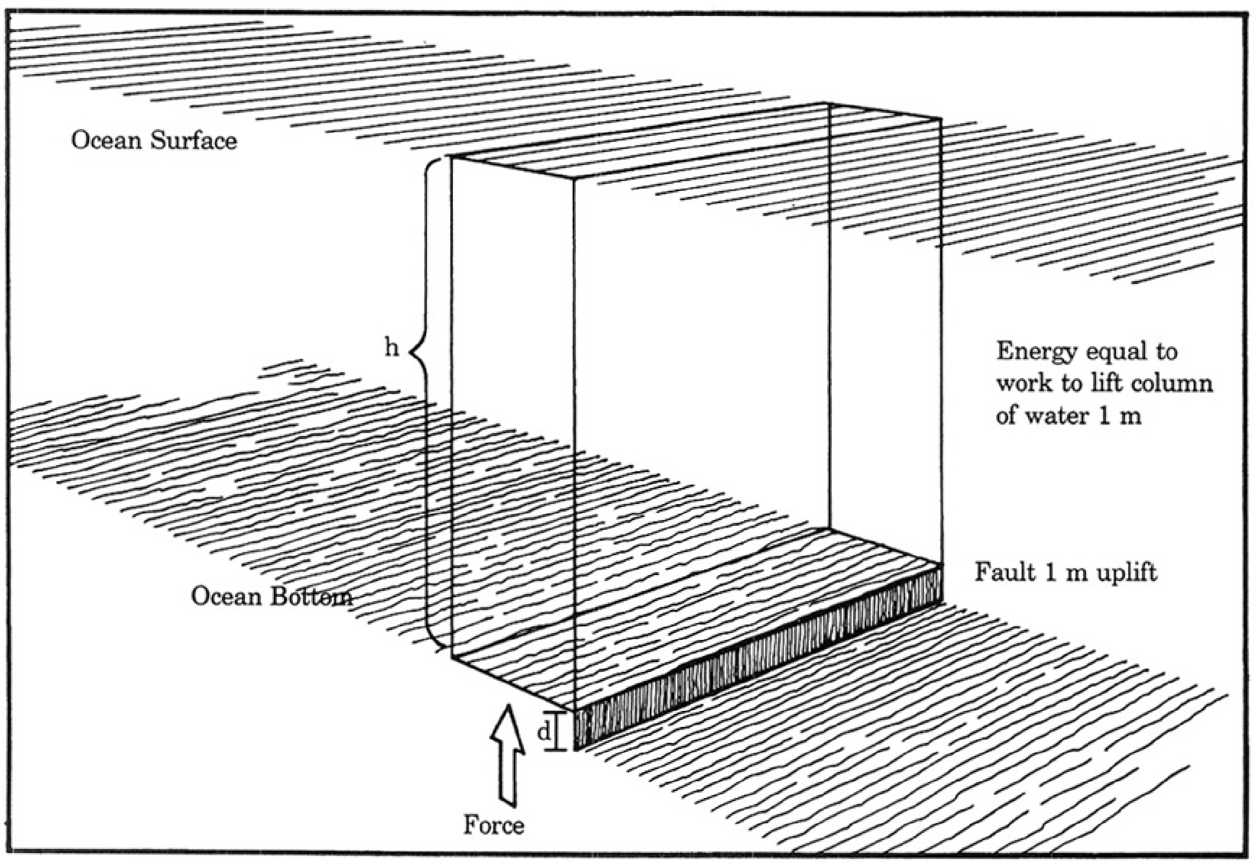
There would be very high and very low water with only minutes in between.

4. What could be done to prepare for this tsunami?

People could be warned to move to high ground.

Wave Characteristics and Energy





d= lift or fall

Seismic Sea Waves Energy Analysis

Name ____ Date ___________________

To calculate the minimum energy needed to cause an average seismic sea wave, we can calculate the work needed to give a particular volume of ocean water some gravitational potential energy. In essence, this means calculating the product of the force needed to lift a particular volume of water and the height to which it is lifted. Using the average values from tsunami research to carry out the following steps, calculate the energy released by an earthquake on the sea floor that starts a seismic sea wave.

1. What is the average sea floor area that moves in an earthquake that results in a seismic sea wave?

2. Knowing that the average ocean depth (h) is 3.8 km, what volume (V) of water is moved in the disturbance that causes a seismic sea wave? (Use the formula V = Ah.)

3. This volume of ocean water has a certain mass. Knowing the density (D) of ocean water to be 1.03 kg/m^3, calculate the mass (m) of the water moved by the quake. (Use the formula m = DV.)
***(note:** 1 $km^3 = 1 \times 10^9$ m^3)*

4. To lift that mass of ocean water requires a force that is at least equal to water's weight. Using 9.8 m/s^2 as the acceleration due to gravity (g), calculate the force (F) needed to lift that much ocean water.

5. Supposing that volume of ocean water is lifted an average height (d) of one meter, how much work (W) is done? This value represents the energy imparted to the seismic sea wave by the earthquake.

6. How much energy is this in equivalent tons of TNT? 1 Ton TNT = 4.18×10^9 Joules

7. Imagine this much energy spreading over a great area, but then being applied to say only 3.8 meters of water instead of 3.8 kilometers. How high might the 3.8 meters of water be lifted?

Seismic Sea Waves Energy Analysis (key)

1. What is the average sea floor area that moves in an earthquake that results in a seismic sea wave?

$$A = 20{,}000\ km^2$$

2. Knowing that the average ocean depth (h) is 3.8 km, what volume (V) of water is moved in the disturbance that causes a seismic sea wave?

Volume of seawater: $V = Ah = (20{,}000\ km^2)(3.8\ km) = 7.6 \times 10^4\ km^3$
$= 76{,}000\ km$

3. This volume of ocean water has a certain mass. Knowing the density (D) of ocean water to be 1.03 kg/m^3, calculate the mass (m) of the water moved by the quake. To convert km^3 to m^3, multiply by 10 m^3/km^3.

Density of seawater: $D = 1.03 \times 10^3\ kg/m^3$
Mass of seawater lifted:
$m = DV = (1.03 \times 10^3\ kg/m^3)(7.6 \times 10^4\ km^3) = (1.03 \times 10^3\ kg/m^3)\ (7.6 \times 10^4\ km^3)\ (10^9\ m^3/km^3)$
7.6×10^{16} *kg or 78 trillion metric tons*
(**note**: $1\ km^3 = 1 \times 10^9 m^3$)

4. To lift that mass of ocean water requires a force that is at least equal to water's weight. Using 9.8 ms^2 as the acceleration due to gravity (g), calculate the force (F) needed to lift that much ocean water.

Acceleration due to gravity: $g = 9.8\ m/s^2$
Force due to gravity or weight of seawater:
$F = mg = (7.8 \times 10^{16}\ kg)(9.8\ m/s^2) = 7.6 \times 10^{17}$ *Newtons*

5. Supposing that volume of ocean water is lifted an average height (d) of one meter, how much work (W) is done? This value represents the energy imparted to the seismic sea wave by the earthquake.

Distance lifted: $d = 1\ m$
Work done against gravity:

$$W = Fd = (7.6 \times 10^{17} N)(1\ m) = 7.6 \times 10^{17} \text{ Joules.}$$

6. How much energy is this in equivalent tons of TNT?

Conversion factor: 4.18×10^9 Joules = 1 Ton TNT

$$W = \text{Energy} = (7.6 \times 10^{17} \text{ Joules})\ (1 \text{ Ton TNT}/4.18 \times 10^9 \text{ Joules})$$

$$\text{Energy} = 1.8 \times 10^8 \text{ Tons TNT or 180 Megatons TNT}$$

7. Imagine this much energy spreading over a great area, but then being applied to say only 3.8 meters of water instead of 3.8 kilometers. How high might the 3.8 meters of water be lifted?

If all the energy were applied to only 3.8 meters of water ($1/1{,}000^{th}$), then the water would rise 1,000 meters instead of only one meter. The energy spreads out very rapidly, so maybe only $1/100^{th}$ of the energy reaches the 3.8 meters of water. In this case the water would rise 30 meters—quite a sizeable wave.

Seismic Sea Wave Research and Report Form

Name ____ Date ____________________

Event

____
____
____
____

Cause

____
____
____
____

Characteristics of the tsunami

____
____
____
____

Damage

____
____
____
____

What could have been done to prevent the damage?

____
____
____
____

Information Source

Title: ____

Author: ____

Publisher and place of publication: __________________________

Date: ______________________

Grading Matrix

Score 4 points
Students clearly communicate all the facts about their event, covering each of the categories on the Seismic Sea Wave Research and Report Form. While reporting the wave's characteristics and energy, students connect the Wave Characteristics and Effects activity sheet and the Energy Analysis activity to their event. The students employ logical thought processes and a knowledge of today's safety practices in their discussion of damage prevention. They use some visual method of communicating their ideas, such as the board, an overhead, a video, a poster, or a demonstration.

Score 3 points
Students clearly communicate all the facts about their event, covering each of the categories on the Seismic Sea Wave Research and Report Form. They do not effectively connect the Wave Characteristics and Effects activity sheet and the Energy Analysis activity to their event. The students' discussion of preventive measures is good. They use the board, an overhead, a video, a poster, or a demonstration in their report.

Score 2 points
Students clearly communicate all the facts about their event, covering each of the categories on the Seismic Sea Wave Research and Report Form. They superficially mention wave characteristics, wave energy, and preventive measures, or they cover one of these three, but not the others. They rely mainly on the spoken word to communicate their information and ideas.

Score 1 point
Students report the facts of their event by reading directly from the Seismic Sea Wave Research and Report Form. They hardly mention wave characteristics and energy. The discussion of preventive measures, if any, is incomplete. They do not use any visual communication aides.

Score 0 points
Students report incorrect information. The Seismic Sea Wave Research and Report Form was poorly completed and the presentation to the class is poor. Statements about the wave's characteristics, its energy, and damage prevention are missing or inaccurate.

2.5

QUAKE–Smart Siting

RATIONALE

City planners, developers, builders, and buyers need information about soil and subsoil geology in order to choose sites and design structures that will best withstand ground shaking and other earthquake hazards.

FOCUS QUESTIONS

What are the important geologic considerations when choosing a building site and designing or reinforcing a building for earthquake survivability?

Have these considerations been taken into account in the planning of towns and cities?

OBJECTIVES

Students will:

1. Interpret soil- and earthquake-related geologic maps.
2. Apply these interpretations in choosing a building site and an earthquake-resistant building design.
3. Locate information about the soils and geology of their local community and apply the same process to interpret it.

MATERIALS

- Student copies of Master 2.5a, Background Reading: Site Characteristics
- Unit 1 Resource List
- Master 2.5b, Soil and Geologic Maps and Map Sources
- Student copies of Master 2.5c, Surface Map, Soil Map, Geologic Map, and Hazard Map (4 pages)
- Transparencies made from Master 2.5c, Surface Map, Soil Map, Geologic Map, and Hazard Map (4 pages)
- Overhead projector
- Local map prepared in Unit 1

TEACHING CLUES AND CUES

Sample maps are provided so students can do this activity without any special preparation. However, the activity will be most meaningful to students if they can relate it to their own area. Master 2.5b, Soil and Geologic Maps and Map Sources, suggests types of maps that would be appropriate and where to get them. The Unit 1 resource list suggests many other. sources. if you have trouble locating maps, call your county or state geology office or the USDA Soil Service and ask for help.

PROCEDURE

Teacher Preparation *(optional but highly recommended)*
If at all possible, gather a selection of local geologic and soil maps in advance. Make student copies of these maps or the appropriate portions of them. If you are not familiar with maps of this type, invite a local geologist or soil scientist to explain them.

A. Introduction
Have students read Master 2.5a, Background Reading: Site Characteristics, as homework, or read it with them in class. Explain and amplify any unfamiliar terms. Discuss the relationship between soils, subsoil geology, and the suitability of a site for building. Explain that the locations of roads, utility lines, reservoirs, and other facilities also involve seismic considerations.

B. Lesson Development
1. Divide students into small groups. Give each group one copy of Master 2.5c, Surface Map, Soil Map, Geologic Map, and Hazard Map (4 pages). Use the map keys to review the special symbols and markings on each map. Instruct students to interpret the information shown on the specialized maps and transfer it to the surface map.

2. As a class, discuss what type of building would be most earthquake resistant in each area of the maps the groups have developed. Ask: Are there some areas where construction is not advisable no matter what the building materials? Instruct students to add these notations to the maps.

3. When all the maps have been completed, site hazards have been noted, and construction recommendations have been made, regroup students into three or four large groups. Within each large group, students can quiz each other about the potential of various sites on their maps.

4. Ask for a volunteer from each large group to report on the group's findings and recommendations. Ask students: What would be the best way to share your recommendations if these maps represented your own area of the country?

C. Conclusion
Stack the three specialized maps on the projector at the same time so the various kinds of information are all displayed simultaneously. Discuss the conclusions that students have drawn and answer any questions. Extend the discussion to the geologic history and hazard potential of your own region.

(optional but highly recommended)
Direct students' attention to the local map they prepared in Unit 1. Have them follow the process they used above to transfer information from local soil maps to the classroom map, noting any implications for building and the location of critical facilities. If this process arouses concerns about safety during an earthquake, ask students to contact the local officials they interviewed in Unit 1 to express their concerns and find out if these concerns have been taken into consideration. Ask these students to report back to the class on what they learn. ▲

VOCABULARY

Fault: a break or fracture in Earth's crust along which movement has taken place.

Landfill: a site where soil has been deposited by artificial means—often, where garbage or rubbish has been disposed of, then covered with dirt and compacted.

Landslide: an abrupt movement of soil and bedrock downhill in response to gravity. Landslides can be triggered by an earthquake or other natural causes.

Liquefaction: the process in which a solid (soil) takes on the characteristics of a liquid as a result of an increase in pore pressure and a reduction in stress.

Sedimentary deposits: accumulation of solid particles that originated from the weathering of rocks and that have been transported or deposited by wind, water, and ice.

Seismic: of or having to do with earthquakes.

Slump: a type of landslide in which a block of rock or soil moves along a curved surface and rotates.

Tsunami: a potentially destructive ocean wave created by an earthquake or other large-scale disturbance of the ocean floor; a seismic sea wave. This Japanese word has the same form in both the singular and the plural.

"Earthquakes don't kill people, buildings do."

Architects and engineers consider this a fair one-sentence summary of earthquake-related deaths, injuries, and damage. Yet, underneath every building is the Earth, which can shake and damage or destroy the building. In the final analysis, the cause of the death and destruction may not be the earthquake or the building, but rather someone's lack of knowledge about the soil and subsoil under the building. Much of the scientific study surrounding earthquakes is focused on the geological characteristics of building sites, the relationship of building sites to earthquake damage, and how buildings respond to ground shaking induced by earthquakes. Location is just as important as building design for making sure that a building can survive an earthquake. Geological site considerations include the location and history of faults, sedimentary deposits, landfill, liquefaction, steep slopes and landslides, tsunami, and human-made hazards.

Faults: Displacement and Ground Shaking

Earthquakes happen when two sides of a fault are displaced, releasing energy in waves. Buildings can be damaged either by direct displacement on the fault or by ground shaking.

Geologists have mapped the locations of many of the most dangerous fault zones in the U.S., yet many faults are not yet recognized. A building within a fault zone can be severely damaged by an earthquake on that fault, but this kind of damage is rare. Most buildings are not in fault zones, and the recurrence interval for any particular fault may be hundreds or thousands of years. The most common cause of damage in earthquakes is the ground shaking caused by the earthquake waves. These attenuate, or die off, with distance, so the two most important factors controlling the amount of shaking are the magnitude of the earthquake and the distance of the building from the fault.

The distance from the fault, not from the epicenter, determines the amount of damage. Energy is produced by all the parts of the fault that move in an earthquake. Because in big earthquakes the fault can be hundreds of miles long, a structure may be hundreds of miles from the epicenter and still be on top of the quake's impact zone.

Several other factors can affect the amount of shaking. Waves do not travel evenly in all directions from the fault, so the orientation of the fault and the way in which displacement on the fault occurs can change the characteristics of the waves. Even more important are variations in local topography—the lay of the land—including the subsoil layers, which may trap or amplify seismic energy, and the type of rock and soil that underlie buildings.

Sediments and Landfill

Ground shaking is greatest on soil that has arrived in place fairly recently, whether it was put there by natural processes (in which case, geologists call it *sediment*) or by artificial ones (in which case, it is called *landfill*). Unfortunately, most of the world's urban centers are sited on relatively young, loose, sedimentary deposits. Sediment age and particle size are important in predicting how soil will respond to shaking during an earthquake. Areas near the shores of rivers and oceans are especially likely to contain young sediments washed there by the water.

Structures located on former watercourses (such as old river beds) or on sites that have been artificially filled with sand dredged up from the bottom of a body of water are among the worst locations for construction in earthquake country because the soil can shift so easily. In Mexico's devastating 1985 earthquake, Mexico City, 320 km (200 miles) from the epicenter, suffered far more damage than the shoreline towns closer to the epicenter. The shoreline is made of solid rock, but Mexico City is built on the sediments of an ancient lakebed.

Old watercourses are usually low and wet, so they are frequently filled when someone wants new land to build on and sell. Landfill is usually a mixture of soil, rock, and decaying organic material in particles of varying sizes.

Because it is not natural to the area where it has been put, landfill in one spot is likely to be of a different composition from landfill in another spot nearby. When seismic waves are transmitted through landfill, they are amplified and their period is lengthened. Long earthquake waves are particularly destructive to some types of surface structures. Landfills commonly will settle and sink during a strong earthquake.

Liquefaction

Whenever poorly consolidated soil or fine sand becomes saturated, an earthquake is likely to cause soil liquefaction. Earthquake vibrations compact the soil, causing water mixed with sand to flow upward. Structures may settle several feet or even topple, causing considerable damage. In a related phenomenon, sandy or muddy soils may behave like liquids, flowing out onto the surface as sand boils or mud boils.

Slopes and Landslides

Structures on cliffs and ridges are also at high risk for earthquake damage, even if they are built on strong bedrock. Earthquake waves appear to be reflected and amplified by topographic highs like cliffs and ridges. Earthquakes also dramatically increase the potential for landslides in areas where landslides are common, such as those where sedimentary rocks lie just under the soil. The probability of an earthquake-related landslide depends on the strength of the slope materials, the steepness of the slope, and the extent and duration of ground shaking. Structures on cliffs and ridges need to be designed to the highest earthquake standards, and should be fully insured.

Tsunami

Tsunami are caused by faulting and the abrupt movement of the ocean floor during an underwater earthquake. A wave generated by this movement can travel as fast as 640 km/hr (400 mph) on the open ocean, where it may not be much above normal height. When it approaches the shore, however, it may attain a height of 15-20 m (50 feet)—in some cases, even 32 m. Tsunami present a distinct hazard to low-lying coastal areas, particularly the west and northwest shorelines along the western North American coast and the northerly facing coast of Hawaii. Low-lying waterfront properties in these areas are at high risk from tsunami.

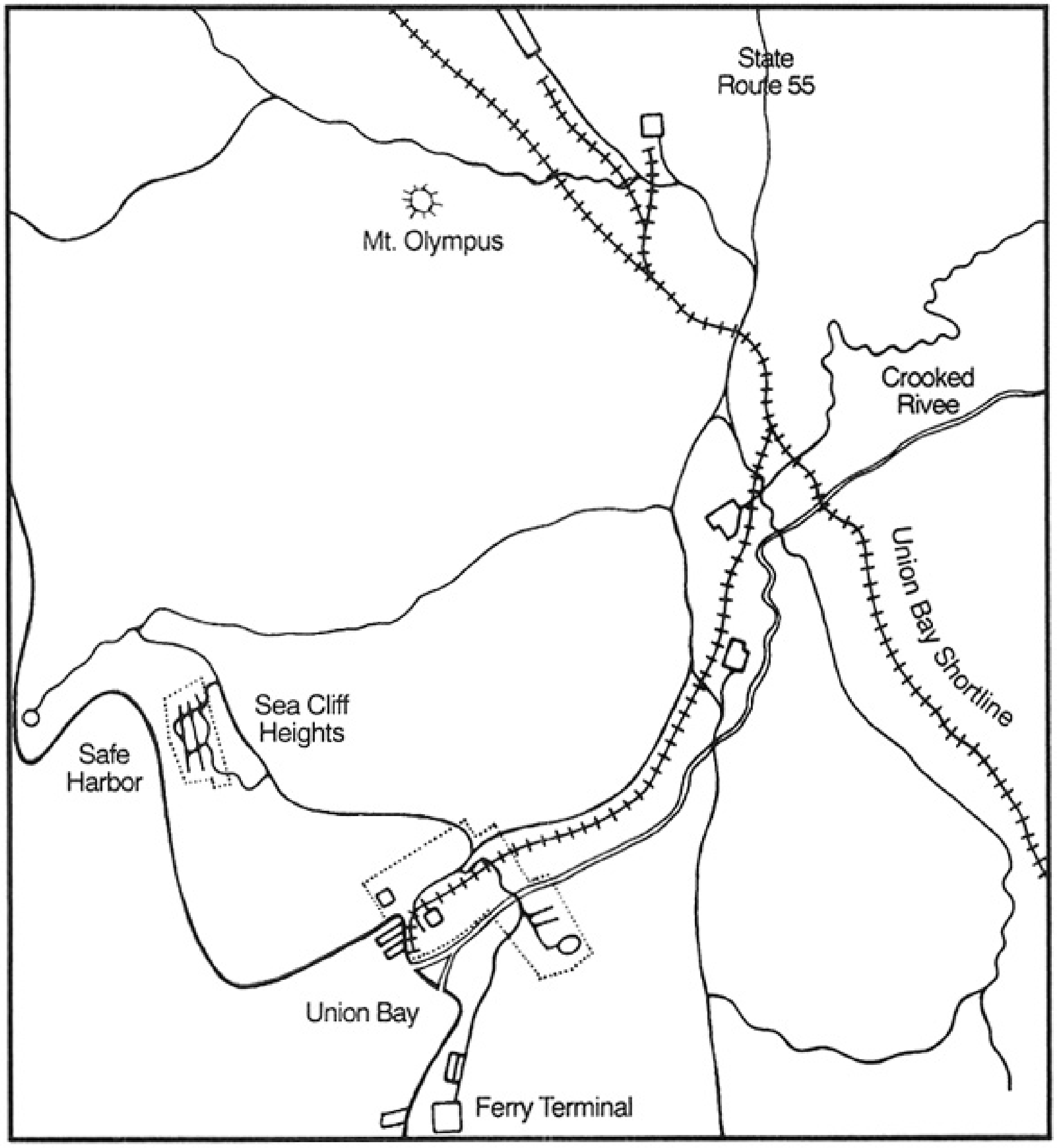
Human-Made Structures

Human-made structures, such as dams, reservoirs, water tanks, and tall buildings, can present special earthquake hazards, and need to be considered during site selection. Every building decision needs to consider the exposure to geologic hazard and the probability of an earthquake, bearing in mind that earthquakes are possible anywhere in the world at any time.

Soil and Geologic Maps and Map Sources

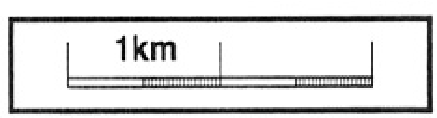
- USGS topographical maps of your area
- Detailed USGS seismic maps that specifically identify earthquake fault traces (available only for areas of high seismic risk)
- Maps issued by state departments of geology or natural resources
- Land use policy or development maps, available from county or city zoning offices. The use of these maps is mandatory for all nonresidential and large-scale residential construction. They may be referred to as "special studies zones" maps
- Seismic risk maps. These are based on the location, number, and magnitude of historic earthquake events that have taken place and been recorded during the last 200 years
- Maps indicating areas of structurally defective grounds, generally developed by state or local agencies to include (a) poor soils and (b) landslide areas
- Landslide susceptibility maps, available from USGS for specific regions in the U.S. The U.S. Department of Housing and Urban Development also has data and maps of landslide problems.
- Maps noting geologic hazards; may he included in your local building codes
- Microzonation maps include data on the anticipated maximum earthquake intensity, active faults, geologic units, special studies zones, ground response, liquefaction susceptibility, landslide susceptibility, and zones of potential tsunami inundation. Available from zoning offices.
- Soil studies of the area produced for agricultural purposes, either by USDA or local agencies
- Soil maps produced by the Soil Conservation Service

Surface Map

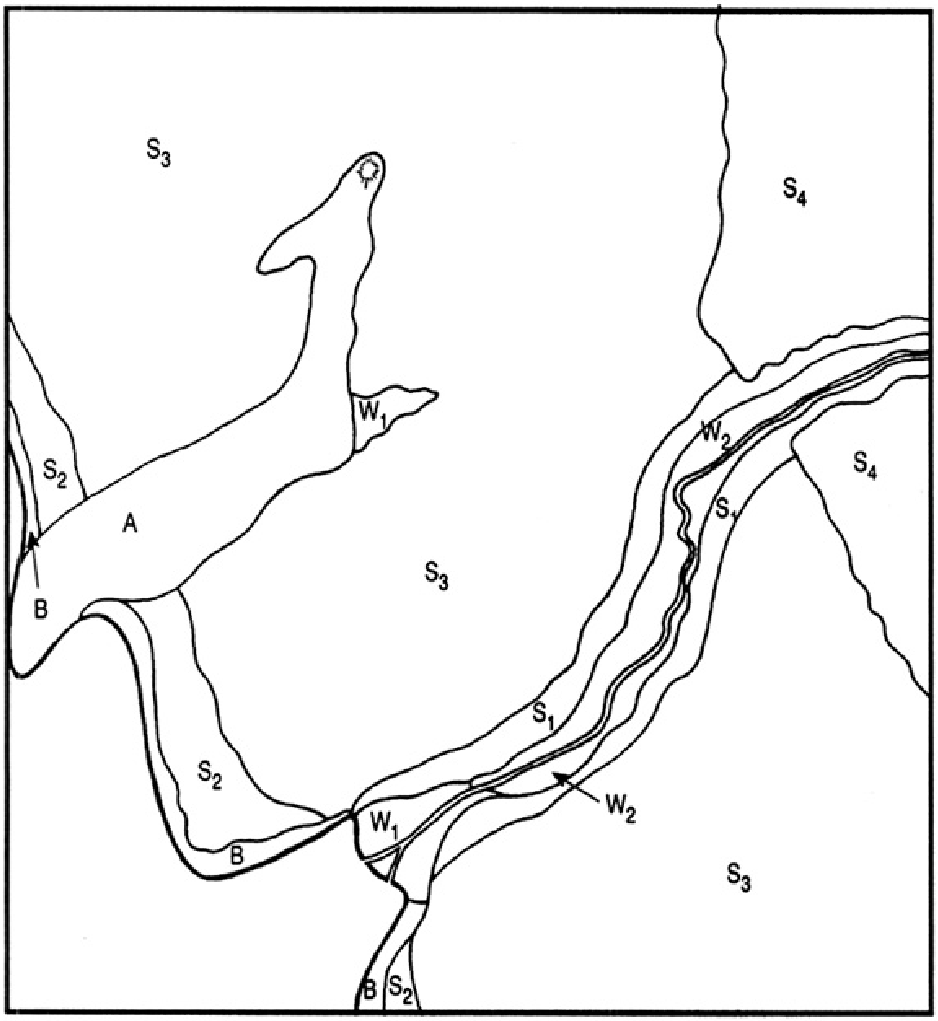


Map Key

	Railroad
	Highway
	City Limits
	Building
	River



Soil Map



Map Key

A – exposed bedrock

B – beach and dune sand

W_1 – saturated soils, fine grained

W_2 – wet soils with seasonal fluctuation in moisture content, fine to medium texture

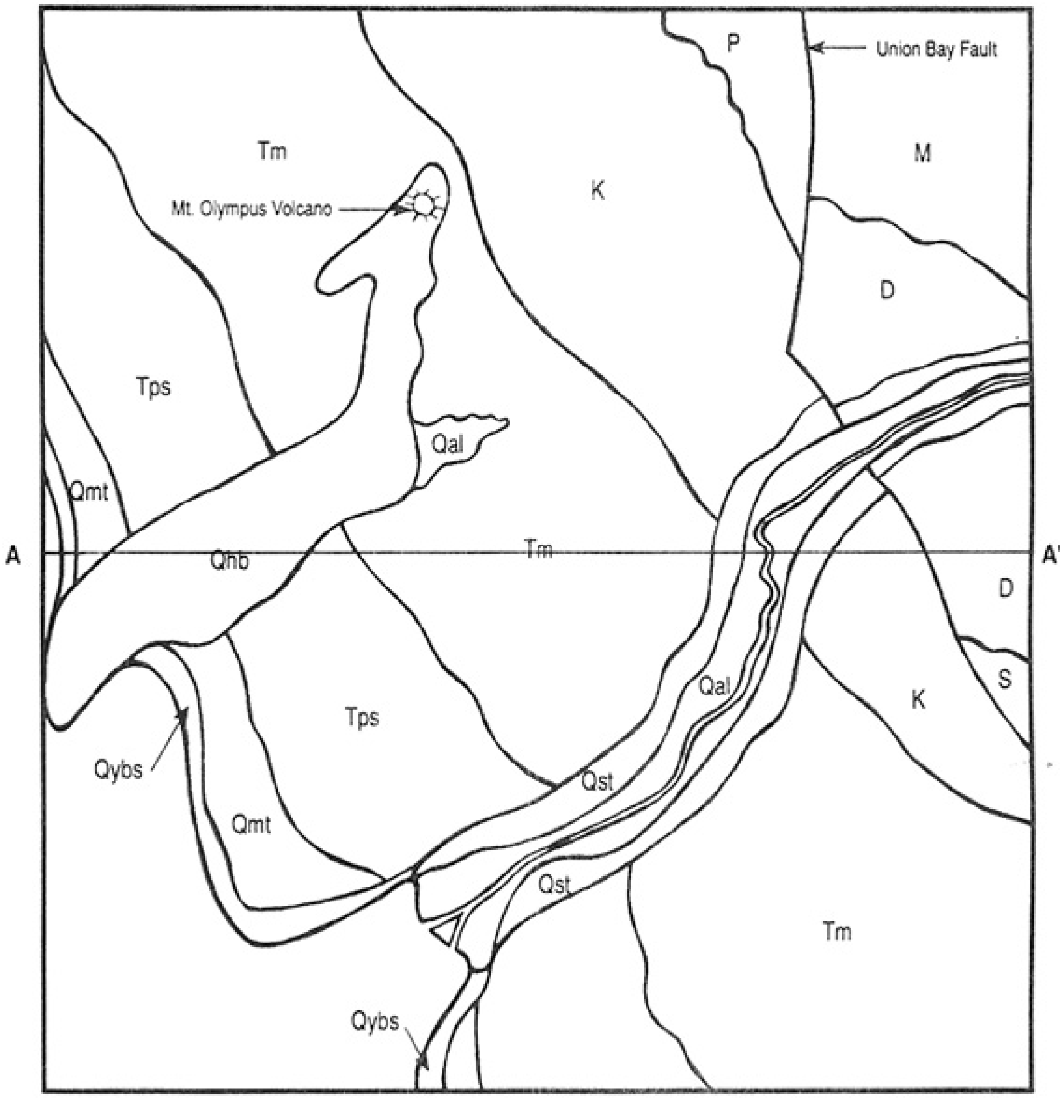
S_1 – thin gravely soils

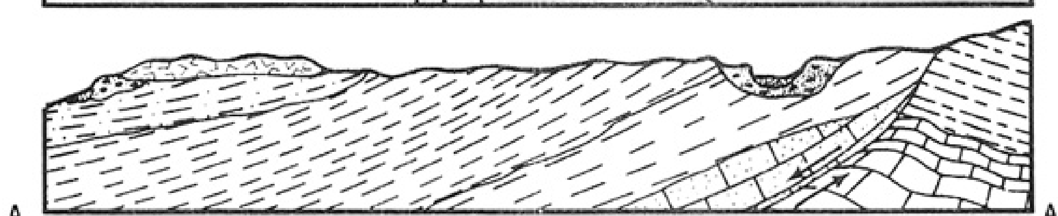
S_2 – thin sandy soils

S_3 – loam 1.3 to 3 m (4 to 6 ft.) thick on gentle terrain, good for farming

S_4 – sandy, rocky soils .3 to 1 m (1 to 3 ft.) ft. thick on moderate to steep terrain, mostly forested

Geologic Map



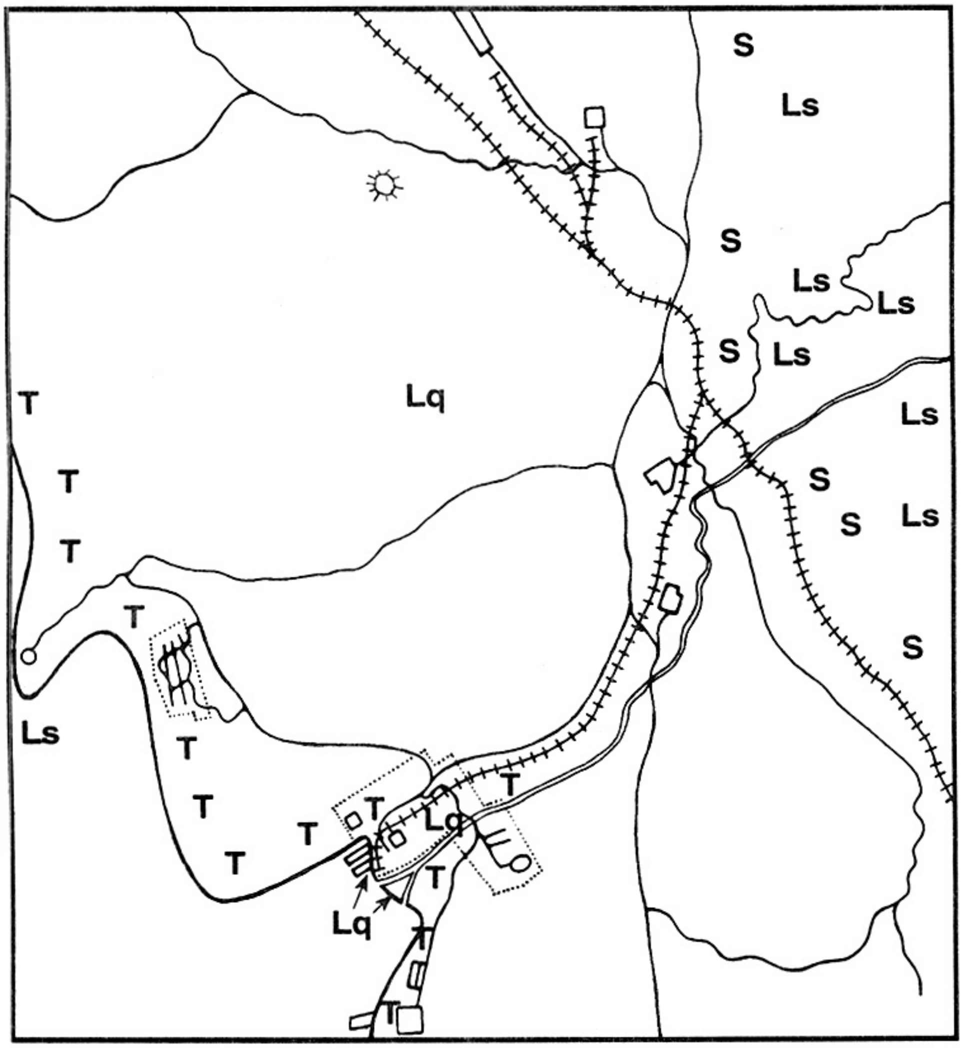


Cross Section

Map Key

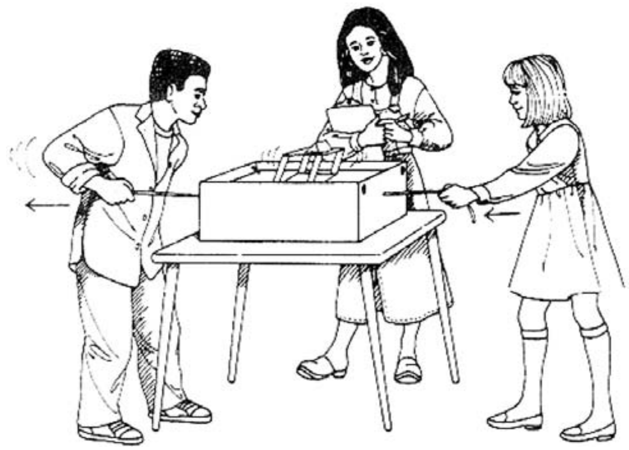
- **Qybs** – young beach sediments, mostly sand, some reworked by wind
- **Qal** – floodplain and delta sediments, clay, silt, and fine sand
- **Qhb** – Holocene basalt flow
- **Qmt** – marine terrace deposits, sand, and gravel
- **Qst** – stream terraces, gravel
- **Tps** – Pliocene siltstone
- **Tm** – Miocene shale with several lignite beds
- **K** – Cretaceous shale with thin coal beds
- **P** – Permian sandy limestone
- M – Mississippian limestone
- D – Devonian shale
- S – Silurian rocks

Hazard Map



Map Key

Ls – landslide hazard
Lq – liquefaction hazard
S – slump hazard
T – tsunami hazard



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NONPRINT MEDIA

California Earthquake Education Project. Earthquake kits and group materials. Lawrence Hall of Science, University of California, Berkeley, CA 94720; 415/327-6017.

The Drift Globe. Burlington, NC: Omni Resources, Inc. (919/227-8300). A 12"-diameter globe with velcro fasteners and velcro continents. Instruction guide is illustrated with cartoons.

The Earthquake Connection. A live-action video in two parts. Available from Ward's Natural Science Establishment, Inc., 5100 W. Henrietta Road, PO Box 92912, Rochester, NY; 800-962-2660. Ward's also has earthquake filmstrips and slides.

Earthquake Effects: A Computer Animation and Paper Model. U.S. Geological Survey Open-File Report 92-200B, by Tau Rho Alpha, Robert A. Page, and Leslie C. Gordon. Order from U.S. Geological Survey, PO Box 25425, Denver, CO 80225; 303-236-4476.

Earthquake Simulator. A program for the Apple II series. Available from Ward's Natural Science Establishment, Inc., 5100 W. Henrietta Road, PO Box 92912, Rochester, NY; 800-962-2660.

Earthquake Slides. Photographs of earthquake effects, copies of seismograms, and seismicity maps can be obtained from the National Geophysical and Solar Terrestrial Data Center, Code D62, NOAA/EDS, Boulder, CO 80302.

Earthquake Sounds. A cassette tape of sounds recorded in various earthquakes, available with a catalog from Seismological Society of America, 201 Plaza Professional Building, El Cerrito, CA 94530; 415-525-5474.

Earthquakes: Environments and Effects. A 15-minute interactive videotape available from CALEEP, 510-642-8718.

EERI Videotapes and Slide Sets. Oakland, CA: Earthquake Engineering Research Institute. For information, phone 510-451-0905, or fax 510-451-5411.

Steinbrugge Collection. Richmond, CA: Earthquake Engineering Research Center. Over 10,000 photographs and 5,000 slides of earthquake damage. The library will provide copies to teachers and researchers. Call 510-231-9401 for information.

Note: *Many of the references for Unit 3 may also be useful for teaching this unit. Inclusion of materials in these resource listings does not constitute an endorsement by AGU or FEMA.*